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RE: Intermountain IBAM Project
PO: A03-008-413
WO: 50633

SUBJ: Burner Testing

Mr. Ferrara:

As part of its scope of supply to Advanced Burner Technologies (ABT) on this project, Air Monitor (AMC) was to perform both CFD modeling of the installed IBAMs and detailed probe characterization in its airflow test duct.

In order to facilitate the manufacturing schedule for the burners, the CFD modeling was utilized to validate the location selected by ABT for mounting the IBAMs. Of most importance to AMC was examining the proposed location to determine whether the IBAMs would be subjected to reversing or stagnated airflow. A twelve point modeling matrix is shown in CFD Modeling Matrix. As a result of the initial round of CFD modeling, the IBAM location was moved a couple of inches further away from the inlet perforated plate, sections of the divider between the burner's inner and outer passages were removed by ABT, and a pair of CFD models was re-run to verify the results of the burner modifications. Examples of the initial and final CFD modeling are attached. Based upon the final CFD results, AMC elected to increase the number of sensing holes near the mounting end of the IBAMs.

In preparation for airflow testing, AMC constructed a full-scale functional replica of the ABT burner and mounted three IBAMs in accordance with the CFD testing. Test Matrix_R0 was developed, consisting of three outer damper positions, two inner damper positions, three swirl angles and three airflow rates. The low, mid, and high airflow rates of 9663, 13,805, and 22,087 acfm in the wind tunnel produce the same Reynolds numbers as the design minimum, normal, and maximum flow rates. See Reynolds Number Calculations worksheet.

The results of performing airflow testing per Matrix_R0 are shown in Test Results_R0, clearly showing that the airflow in this burner is dominated by, and a function of the position of the outer damper. After applying a single point best-fit K-factor of 0.4452 to all the data, the outer damper flow measurements in the 4.8 position were 19.92% to 32.55% higher than the test duct (Nozzle Flow), while the outer damper in the 16 position produced results 29.705% to 37.10% lower than the test duct.

Based upon the Test Results R0, AMC elected to expand the original 54 point test matrix to a 135 matrix, adding a third inner damper position (3" open) and two additional outer damper positions (8" and 12" open). The result is the Wind Tunnel Test Matrix_R1.

The additional 81 flow tests were performed, resulting in the Test Results_R1, further confirming the dependency relationship between the outer damper position and the IBAM airflow signal. Using all 135 points of data, a third order polynomial was developed, and specific K-factors for each of the five outer damper positions were calculated. These are shown in the column labeled Curve Fit K-Factor. The result of implementing a curve fit K-factor reduced the +32.55% to –37.10% variance from Test Results_R0 to +8.57% to –8.63% in Test Results_R1.

Further reductions in the range of measurement variance required dividing the 135 points of data into nine groups of fifteen points, each group representing a single combination of inner damper and swirl vane positions, five outer damper positions and three flow rates. A third order polynomial curve fit K-factor was determined for each of the nine groups, reducing the variance to +6.86% to –6.56%. A secondary best-fit K-factor was determined for each group of 15 points, further reducing the overall variance to +3.51% to –3.83%.

Shown below, for Test Results R0 – R2, are all formulas for converting the IBAM differential pressure signal to airflow in lbs./hr.

R0. Single point, best-fit K-factor for 54 points

$$Q_{acfm} = 9128.483276 \; x \sqrt{\frac{DP \; x \; Ta}{Pa}}$$

Where,

DP = Differential Pressure produced by IBAM in Inches of W.C.
Pa = Actual absolute duct pressure in Inches of Mercury (Hg)
Ta = Actual absolute air temperature (460+ duct temp in °F)

$$Lb \,/\, hr = 79.54675312 \quad x \; Q_{acfm} \; x \; \frac{Pa}{Ta}$$

R1. 3rd order best-fit polynomial K-factor for 135 points, based upon outer damper position

$$Q_{acfm} = 20504.23018 \; x \; K \; x \sqrt{\frac{DP \; x \; Ta}{Pa}}$$

Where,

DP = Differential Pressure produced by IBAM in Inches of W.C.
Pa = Actual absolute duct pressure in Inches of Mercury (Hg).
Ta = Actual absolute air temperature (460+ duct temp in °F)
K = Probe Coefficient derived from the following equation

$$K = -0.0005066375P^3 + 0.0149206078P^2 - 1.1016842562P + 0.5514334077$$

Where P = Outer Damper position in inches "Open".

$$Lb \,/\, hr = 79.54675312 \;\; x \; Q_{acfm} \; x \; \frac{Pa}{Ta}$$

R2. Nine, 3rd order best-fit polynomial primary K-factors based upon outer damper position, combined with corresponding best-fit line secondary K-factors

a. Inner @ 1", Vanes @ 30°

$$Primary\ Correction:\ Q1_{acfm} = 20504.23018\ x\ K1\sqrt{\frac{DP\ x\ Ta}{Pa}}$$

Where,

DP = Differential Pressure Produced by IBAM in Inches of W.C.
Pa = Actual absolute duct pressure in Inches of Mercury (Hg).
Ta = Actual absolute air temperature (460+ duct temp in °F)
K1 = Probe Coefficient derived from the following equation.

$$K1 = -0.0005160698P^3 + 0.0151109169P^2 - 0.1021109736P + 0.5479363073$$

Where P = Outer Damper position in inches "Open".

$$Second\ Correction:\ Q2_{acfm} = 0.93213\ x\ Q1_{acfm} + 938.61252$$

Where,

$Q2_{acfm}$ is the final corrected flow in acfm

$$Lb/hr = 79.54675312\ x\ Q2_{acfm}\ x\ \frac{Pa}{Ta}$$

b. Inner @ 3", Vanes @ 30°

$$K1 = -0.0005668957P^3 + 0.0170757815P^2 - 0.1238078901P + 0.6258513938$$
$$Second\ Correction:\ Q2_{acfm} = 0.93369\ x\ Q1_{acfm} + 917.90133$$

c. Inner @ 5", Vanes @ 30°

$$K1 = -0.0005744093P3 + 0.0174543625P2 - 0.1287841730P + 0.6484898817$$
$$Second\ Correction:\ Q2_{acfm} = 0.92983\ x\ Q1_{acfm} + 966.24889$$

d. Inner @ 1", Vanes @ 45°

$$K1 = -0.0004485864P^3 + 0.0128252354P^2 - 0.0793247289P + 0.4738300277$$
$$Second\ Correction:\ Q2_{acfm} = 0.92780\ x\ Q1_{acfm} + 998.99211$$

e. Inner @ 3", Vanes @ 45°

$$K1 = -0.0005125018P^3 + 0.0151754738P^2 - 0.1049700879P + 0.5616551006$$
$$Second\ Correction:\ Q2_{acfm} = 0.3599\ x\ Q1_{acfm} + 885.07490$$

f. Inner @ 5", Vanes @ 45°

$$K1 = -0.0005314237P^3 + 0.0157184118P^2 - 0.1088960787P + 0.5723255306$$
$$Second\ Correction: Q2_{acfm} = 0.92779\ x\ Q1_{acfm} + 996.21098$$

g. Inner @ 1", Vanes @ 60°

$$K1 = -0.0004109098P^3 + 0.0116702447P^2 - 0.0696424993P + 0.4477972024$$
$$Second\ Correction: Q2_{acfm} = 0.92787\ x\ Q1_{acfm} + 998.71141$$

h. Inner @ 3", Vanes @ 60°

$$K1 = -0.0005153999P^3 + 0.0151221072P^2 - 0.1038177221P + 0.5568244679$$
$$Second\ Correction: Q2_{acfm} = 0.92290\ x\ Q1_{acfm} + 1065.29025$$

i. Inner @ 5", Vanes @ 60°

$$K1 = -0.0004835412P^3 + 0.0141329363P^2 - 0.0938041524P + 0.5281907566$$
$$Second\ Correction: Q2_{acfm} = 0.92236\ x\ Q1_{acfm} + 1071.22493$$

In conclusion, this report demonstrates the benefits of using both CFD modeling and actual airflow testing. CFD modeling proved beneficial in determining the IBAM location and pointing out beneficial burner modification; but if used alone, there would have been no way to quantify the unique relationship between flow probe and actual burner airflow at various combination of burner adjustment. The result would have been measurement errors as great as ±37%.

Sincerely,

AIR MONITOR CORPORATION

Paresh Davé
Manager, Applications Engineering

cc: Mr. Jerry Finlinson
Intermountain Generating Power